oscillates and, if protein levels also oscillate, then cells in the posterior presomitic mesoderm will go through periods of low *Snail* activity yet they do not undergo a mesenchymal to epithelial transition [3]. This could be due to high levels of *Fgf* signaling which may modulate the cellular response to *Snail* in the posterior presomitic mesoderm [19,20]. Alternatively, the absence of *Snail* may be insufficient to elicit a mesenchymal to epithelial transition as genes which are only expressed in the anterior presomitic mesoderm may be required.

Taken together, *Snail* appears to have three successive functions in the somite anlagen. Early on, *Snail* may promote the epithelial to mesenchymal transition as cells enter the presomitic mesoderm during gastrulation; later, it links *Wnt* and *Notch* signaling within the somite clock and finally it regulates the mesenchymal to epithelial transition during morphological segmentation [3,5,6]. Exactly how *Snail* performs all of these functions awaits further examination.

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DOI: 10.1016/j.cub.2006.04.007

Insect Vision: Remembering the Shape of Things

How does the nervous system store a newly experienced visual pattern, and how is that pattern subsequently made available for recognition? Recent work in *Drosophila* suggests that specific pattern features are stored separately in the nervous system.

Alexander Katsov and Thomas R. Clandinin

We have only a limited understanding of how sensory cues in the environment are represented and remembered by the nervous system. Our ignorance is particularly acute in the context of complex signals typical of the visual world: we take for granted our ability to associate particular scenes with events in our past, yet the neural mechanisms by which we perceive and remember them are almost completely mysterious. Recent work in the fruitfly *Drosophila* has begun to cast light on both of these processes.

Insects are thought to extract only a limited set of features from the shapes and patterns they encounter [1–3]. As a result, a fly's perception of shape may be very different from our own. Nevertheless, flies can associate specific visual patterns with adjustments to their own behavior. Given this visually directed behaviour and the remarkable manipulations of the nervous system that are now possible using recently developed genetic tools, the humble fruitfly offers an

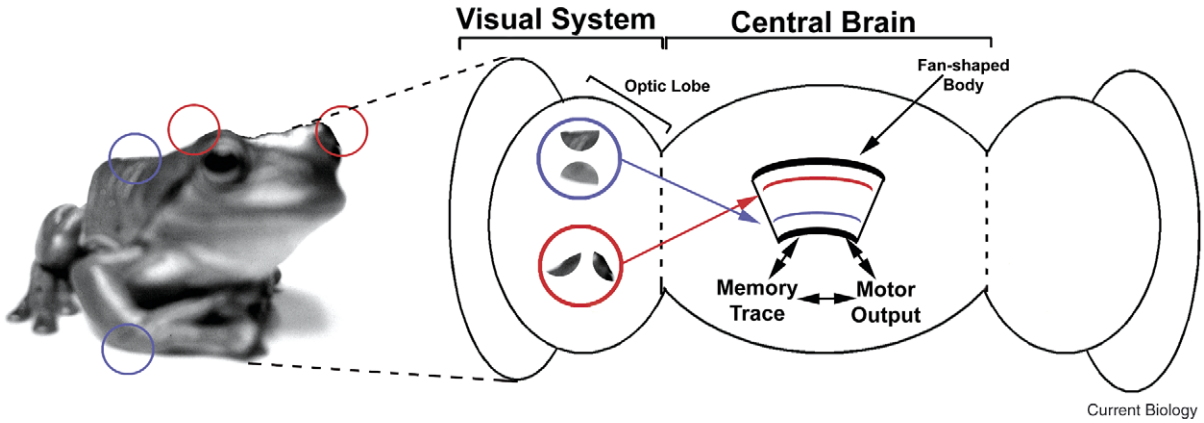

Figure 1. Schematic illustration of the shape processing pathway in the fly suggested by Liu *et al.* [10].

An arbitrary image is first decomposed into component features such as 'elevation' (blue circles) and 'contour orientation' (red circles). This information is passed to specific layers in the fan-shaped body, whose functions are specifically required for the association of their respective features with aversive stimuli such that the motor output of the animal can be altered by training.

unparalleled opportunity for unraveling the principles of visual pattern recognition and memory formation.

Access to these questions became possible with the development of an experimental paradigm examining conditioned pattern avoidance in a flight simulator. In this set-up, a fly is immobilized at the head and thorax and suspended in the air; nevertheless, it can still initiate flight maneuvers spontaneously. With the fly coupled to a torque meter, the rotational component of forces generated by the fly can be measured; this component is interpreted as yaw turns in a virtual flight path [4]. The effect of visual stimuli on this behavior can be examined by surrounding the fly with a drum on which visual stimuli are presented. Two paradigms are widely used: in one, the drum is rotated independently of the fly's reactions, forming a so-called open loop; in the other, torque signals generated by the fly can be used to control drum rotation in a closed circuit [5,6].

A salient feature such as a dark shape on a white background causes the fly to exert torque toward the feature under open-loop conditions, suggesting that the animal is attempting to orient toward the salient object. Under closed loop conditions, the salient feature will typically stabilize in the front or rear quadrant of the fly's visual field [7]. Presented with two or more identical visual features, the fly distributes the amount of time spent fixating each [7,8]. Presented with two different shapes, the fly may, or may not, exhibit a spontaneous preference for one over the other by fixating that shape longer [9]. Such spontaneous preferential fixation suggests that the fly can distinguish the two shapes; however, the absence of spontaneous preference cannot be taken conclusively as an inability to see the two shapes as different [10].

Flies can be conditioned to change their flight simulator behavior using heat as an aversive stimulus [8]. With a conditioning paradigm, it has been possible to explore two kinds of questions. First, what aspects of a visual pattern might a fly perceive? One can imagine extending the kind of conclusion one might draw from a spontaneous preference between two shapes to a learned or conditioned preference: that is, if a fixation preference between two shapes can be modified by conditioning, one can parsimoniously conclude that the fly can see some feature of the two shapes as distinct.

Such a learning paradigm also affords access to a second question: what are the neural substrates of remembering, or expressing, a learned preference for a particular feature? One can envisage two extreme learning strategies the fly might take. In one, the fly might remember only its motor actions; in the other, the fly might register only features of the visual stimulus, divorced from its motor activities. It should come as no surprise that flies appear to adopt a hybrid strategy. There is evidence that conditioning in this paradigm employs elements of 'learning by doing'. In one experiment, a sequence of visual stimulus displacements and heating episodes generated by one fly's movements was replayed to a second fly, which failed to form the appropriate association from a sequence of events that was successful in conditioning the first [8]. Remarkably, flies can also keep track of an arbitrary position in a featureless environment, perhaps using a mechanism that records their turning history [11]. Together these previous studies suggested that fly behavior in the flight simulator harbors clues to the neural strategies underlying operant behaviors [12].

In their recent study, Liu *et al.* [10] explored the contribution of a *Drosophila* brain structure previously implicated in motor control to visual pattern-specific aversive conditioning. This new work points to an intriguing link between visual feature processing and parts of a fly's nervous system associated with the motor aspects of operant behavior. A fly was immobilized on a torque meter and presented with a visual stimulus consisting of two shape types, alternating at 90° intervals. For operant conditioning, the fly's yaw

torque controls rotation of the visual stimulus; the fly is heated when a quadrant that contains one of the two shape types rotates into the front part of its visual field (with an identical shape simultaneously entering the rear quadrant). For classical conditioning, the visual stimulus was rotated at a constant rate, independent of the fly's behavior; heating was similarly paired with one of the two stimulus types.

Liu *et al.* [10] found that when neural transmission was disrupted in the adult fly, in a group of cells that included neurons of the central complex, pattern preference was not induced by operant conditioning. The gene *rutabaga*, previously studied in the context of olfactory learning, was found to be necessary for both operant and classical conditioning in this paradigm, as *rutabaga* mutants are incapable of forming a conditioned pattern preference, even though spontaneous pattern discrimination remained intact. Strikingly, expression of a constitutively active protein of the *rutabaga* pathway in neurons that include a subset of central complex neurons disrupted conditioned discrimination between one set of shapes, but not another. Conversely, rescue by expression of wild-type *rutabaga* in the same set of neurons in an otherwise *rutabaga* mutant animal was found to be sufficient to restore conditioned discrimination for the same set of shapes. Using a different driver to drive *rutabaga* rescue in a different set of neurons, which included a different subset of central complex neurons, the authors showed that conditioned discrimination of a different set of shapes could now be restored.

Taking these findings together, Liu *et al.* [10] concluded that the fly's memory traces for distinct visual features are stored in feature-specific circuits, rather than in a "common all-purpose memory center" (Figure 1). It is intriguing that the specificity of feature learning in the context of these experiments may be rendered by a pre-motor center of the fly's brain. It will be interesting to learn whether different elementary features thought to explain conditioned discrimination of different pattern types in the flight simulator — features such as center of gravity, area, or orientation — may be distinguished by subtly different behavioral strategies. To what extent is visual scene segmentation aided by active exploration?

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DOI: 10.1016/j.cub.2006.04.006

Eukaryotic Transcription: What Does It Mean for a Gene to Be 'on'?

Until recently, transcription could only be observed by measuring mRNA production of cell populations, thus obscuring the kinetics at the level of individual transcription events. A new study now shows that eukaryotic transcription, visualised in individual living cells, occurs in bursts — much as it does in prokaryotes.

Ido Golding and Edward C. Cox

When we say a gene is 'on', what do we mean? We usually measure RNA transcripts on large populations of cells, but what would we find if we could look at individual transcripts as they are being made? The simplest kinetics imaginable would be that each initiation event occurred as a simple Poisson process [1], whereby synthesis of individual mRNA molecules was initiated with a constant probability k as a function of time (Figure 1). Genes with high rates of transcription would then have high values for k, while repressed genes would have values close to zero. Thus, when we observe the total mRNA synthesis for a given gene in a population of cells, we would measure constant rates of RNA production [2], and this macroscopic rate would be equal to the microscopic probability per unit time k. This is the simplest model, but transcription dynamics can take on many other, more complex temporal patterns. Until recently, however, observations of transcriptional activity were limited to traditional methods, where mRNA levels were necessarily averaged over large cell populations, typically 10^8–10^9 cells in an experiment with bacteria. Individual events in single living cells could not be studied, and so we could not ask how